THE NICKEL BULLETIN

A SUMMARY OF CURRENT INFORMATION ON NICKEL

JUNE, 1952

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CONVERSIONS

between

HARDNESS AND TENSILE STRENGTH

of

STEELS

ALTHOUGH hardness conversions from one scale to another are not quantitative, the empirical relations which have been determined from time to time give approximations sufficiently close to be useful.

The conversions given in these tables are based on extensive tests on plain carbon and alloy steels mostly in the heat-treated condition. They have proved to be reliable on practically all constructional alloy steels and tool steels in the as-forged, annealed, normalized, and quenched and tempered conditions.

The same degree of accuracy must not be expected from steels which have been heavily cold-worked, or from austenitic steels such as the 18/8 chromium-nickel steels or high manganese steels which have a high response to cold-work.

The relationship between tensile strength and hardness cannot be regarded as accurate, because it is affected by size, mass, composition and method of heat-treatment of the steel. Where more precise factors are required, they should be developed independently from more precise conditions. Despite the unavoidable inaccuracies, the figures have in fact proved valuable as a guide.

Numbers given in bold-face type were prepared jointly by the American Society for Testing Materials (E 48), the American Society for Metals and the Society of Automotive Engineers from data that were carefully checked.

Numbers given in light-face type were taken from earlier tables (1943 S.A.E. Handbook, p. 363) in which relatively minor adjustments were made.

Numbers given in italics are beyond the normal range of the machine. The figures for Tensile Strength were originally estimated in lb./sq. in. Those for tons/sq. in. and kg./sq. mm. were calculated from the lb./sq. in. to the nearest whole number. It may be observed that the factor for conversion from D.P.N. to M.S. (tons/sq. in.) varies from 0·207 at the lower hardnesses to 0·216 at the highest levels. It would be useful therefore to remember the factor 0·21 as giving a rough guide for the ranges in most common use.

Hardness and Tensile Strength Conversions

D.P.N.	R_c	B.H.N.		R_B	Sclero-scope	Tensile Strength			D.P.N.
		Standard Ball	Tungsten Carbide Ball			t.s.i.	1000 p.s.i.	Kg/sq. mm.	
940	68·0	—	—	—	97	—	—	—	940
920	67·5	—	—	—	96	—	—	—	920
900	67·0	—	—	—	95	—	—	—	900
880	66·4	—	767	—	93	—	—	—	880
860	65·9	—	757	—	92	—	—	—	860
840	65·3	—	745	—	91	—	—	—	840
820	64·7	—	733	—	90	—	—	—	820
800	64·0	—	722	—	88	—	—	—	800
780	63·3	—	710	—	87	—	—	—	780
760	62·5	—	698	—	86	—	—	—	760
740	61·8	—	684	—	84	—	—	—	740
720	61·0	—	670	—	83	—	—	—	720
700	60·1	—	656	—	81	—	—	—	700
690	59·7	—	647	—	—	—	—	—	690
680	59·2	—	638	—	80	147	329	231	680
670	58·8	—	630	—	—	145	324	228	670
660	58·3	—	620	—	79	142	319	224	660
650	57·8	—	611	—	—	140	314	221	650
640	57·3	—	601	—	77	138	309	217	640
630	56·8	—	591	—	—	136	304	214	630
620	56·3	—	582	—	75	133	299	210	620
610	55·7	—	573	—	—	131	294	207	610
600	55·2	—	564	—	74	129	289	203	600
590	54·7	—	554	—	—	127	284	200	590
580	54·1	—	545	—	72	125	279	196	580
570	53·6	—	535	—	—	122	274	193	570
560	53·0	—	525	—	71	120	269	189	560
550	52·3	505	517	—	—	118	264	186	550
540	51·7	496	507	—	69	116	260	183	540
530	51·1	488	497	—	—	113	254	179	530
520	50·5	480	488	—	67	112	250	178	520
510	49·8	473	479	—	—	109	244	172	510

Hardness and Tensile Strength Conversions—*continued.*

D.P.N.	R_C	B.H.N.		R_B	Sclero-scope	Tensile Strength			D.P.N.
		Standard Ball	Tungsten Carbide Ball			t.s.i.	1000 p.s.i.	Kg/sq. mm.	
500	**49·1**	**465**	**471**	—	66	107	240	169	**500**
490	**48·4**	**456**	**460**	—	—	105	234	165	**490**
480	**47·7**	**448**	**452**	—	64	103	230	162	**480**
470	**46·9**	**441**	**442**	—	—	100	224	157	**470**
460	**46·1**	**433**	**433**	—	62	98·2	220	155	**460**
450	**45·3**	**425**	**425**	—	—	95·5	214	150	**450**
440	**44·5**	**415**		—	59	93·8	210	148	**440**
430	**43·6**	**405**		—	—	91·1	204	143	**430**
420	**42·7**	**397**		—	57	89·3	200	141	**420**
410	**41·8**	**388**		—	—	87·1	195	137	**410**
400	**40·8**	**379**		—	55	84·8	190	134	**400**
390	**39·8**	**369**		—	—	82·6	185	130	**390**
380	**38·8**	**360**		*110*	52	80·4	180	127	**380**
370	**37·7**	**350**		—	—	78·1	175	123	**370**
360	**36·6**	**341**		*109*	50	75·9	170	120	**360**
350	**35·5**	**331**		—	—	74·1	166	117	**350**
340	**34·4**	**322**		*108*	47	71·9	161	113	**340**
330	**33·3**	**313**		—	—	69·6	156	110	**330**
320	**32·2**	**303**		*107*	45	67·4	151	106	**320**
310	**31·0**	**294**		—	—	65·2	146	103	**310**
300	**29·8**	**284**		—	42	62·9	141	99·1	**300**
295	**29·2**	**280**		*105*	—	62·1	139	97·7	**295**
290	**28·5**	**275**		—	41	60·7	136	95·6	**290**
285	**27·8**	**270**		*104*	—	59·8	134	94·2	**285**
280	**27·1**	**265**		—	40	58·5	131	92·1	**280**
275	**26·4**	**261**		—	—	57·6	129	90·7	**275**
270	**25·6**	**256**		*102*	38	56·3	126	88·6	**270**
265	**24·8**	**252**		—	—	55·4	124	87·2	**265**
260	**24·0**	**247**		*101*	37	54·0	121	85·1	**260**
255	**23·1**	**243**		—	—	53·1	119	83·7	**255**
250	**22·2**	**238**		99·5	36	51·8	116	81·6	**250**
245	**21·3**	**233**		—	—	50·9	114	80·2	**245**

Hardness and Tensile Strength Conversions—*continued.*

D.P.N.	R_C	B.H.N.		R_B	Sclero-scope	Tensile Strength			D.P.N.
		Standard Ball	Tungsten Carbide Ball			t.s.i.	1000 p.s.i.	Kg/sq. mm.	
240	**20·3**	**228**		98·1	34	49·6	111	78·0	**240**
235	—	—		—	—	48·7	109	76·6	**235**
230	*18·0*	**219**		96·7	33	47·3	106	74·5	**230**
225	—	**214**		—	—	46·4	104	73·1	**225**
220	*15·7*	**209**		95·0	32	45·1	101	71·0	**220**
215	—	**204**		—	—	44·2	99	69·6	**215**
210	*13·4*	**200**		93·4	30	43·3	97	68·2	**210**
205	—	**195**		—	—	42·4	95	66·8	**205**
200	*11·0*	**190**		91·5	29	41·1	92	64·7	**200**
195	—	**185**		—	—	40·2	90	63·3	**195**
190	*8·5*	**181**		89·5	28	39·3	88	61·9	**190**
185	—	**176**		—	—	38·4	86	60·5	**185**
180	*6·0*	**171**		87·1	26	37·5	84	59·1	**180**
175	—	**166**		—	—	36·2	81	57·0	**175**
170	*3·0*	**162**		85·0	25	35·3	79	55·5	**170**
165	—	**157**		—	—	34·4	77	54·1	**165**
160	*0·0*	**152**		81·7	24	33·5	75	52·7	**160**
155	—	**148**		—	—	32·6	73	51·3	**155**
150	—	**143**		78·7	22	31·7	71	49·9	**150**
145	—	**138**		—	—	30·4	68	47·8	**145**
140	—	**133**		75·0	21	29·5	66	46·4	**140**
135	—	**128**		—	—	28·6	64	45·0	**135**
130	—	**124**		71·2	20	27·7	62	43·6	**130**
125	—	**119**		—	—	26·8	60	42·2	**125**
120	—	**114**		66·7	—	25·4	57	40·1	**120**
115	—	**110**		—	—	—	—	—	**115**
110	—	**105**		62·3	—	—	—	—	**110**
105	—	**100**		—	—	—	—	—	**105**
100	—	**95**		56·2	—	—	—	—	**100**
95	—	**90**		52·0	—	—	—	—	**95**
90	—	**86**		48·0	—	—	—	—	**90**
85	—	**81**		41·0	—	—	—	—	**85**

ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Powder Metallurgy: Bibliography

C. G. GOETZEL: 'Treatise on Powder Metallurgy. Vol. III. Classified and Annotated Bibliography.' *Published by Interscience Publishers, Inc., New York*, and *Interscience Publishers, Ltd., London*, 1952; 899 pp. Price £8 16s. 0d.

For scope of the series see *Nickel Bulletin*, 1949, vol. 22, Nos. 8-9, p. 131.

Part III, designed essentially as a companion to the earlier volumes, is in two parts, covering, respectively, technical and patent literature: the individual entries include brief annotations on the subject matter of the various items. The *bibliography* is closely classified and cross-referenced, and extensive indexes are provided. Its arrangement, and mode of use, are discussed in the compiler's introduction, which also gives reference to earlier summaries of powder-metallurgy literature.

The present volume is undoubtedly the most comprehensive *bibliography* yet published.

NICKEL

Supply and Use of Nickel: I.M.C. Report

INTERNATIONAL MATERIALS CONFERENCE: 'Utilization of Manganese, Nickel, Cobalt, Tungsten, Molybdenum.' First Report of the Joint Sub-Committee, resulting from meetings held in June and July, 1951. *Published in Washington*, Dec., 1951; 94 pp.

The Report represents the consensus of opinion of the Sub-Committee, which was representative of expert opinion in the following countries: Benelux, Brazil, Canada, France, Federal Republic of Germany, India, Spain, Sweden, United Kingdom, United States.

The following terms of reference, given to the Sub-Committee, broadly indicate the scope of the Report: 'To examine all practicable measures of effecting the highest degree of economy in the use of manganese, nickel, cobalt, tungsten and molybdenum, it being understood that these measures would include all methods which could be adopted by industry for the economical and efficient utilization of these metals and their alloys, for the use of substitutes, and for the better utilization of waste products, together with other methods of conservation that may be suggested.' The agenda drawn up to provide for fulfilment of these requirements covered consideration of ferro-alloys (and other sources of the elements manganese, nickel, cobalt, tungsten and molybdenum); steel and cast iron, embracing (*a*) stainless and heat-resisting steels, (*b*) tool steels, (*c*) low-alloy steels, and (*d*) alloy cast irons; non-ferrous alloys (including those for magnets, hard-facing, heat-resistance, corrosion-resistance, electrical-resistance, constructional alloys based on nickel, copper and aluminium, and materials used for coinage); the pure metals tungsten, molybdenum and nickel, including nickel- and nickel-alloy-clad products and nickel plating; catalysts, and chemicals. Each of these items was dealt with from the three aspects of standard materials; substitution and limitation; salvage and scrap. Substitution and limitation were treated with special relation to end-uses. For details of the recommendations made with regard to the individual materials the original must be consulted. It is emphasized by the Committee that the Report should be considered as an interim one, pending the availability of further statistical information without which it is impossible to make the balanced assessment of the position required as a basis for recommendations on conservation.

Spectrophotometric Determination of Nickel in Steel

M. JEAN: 'Spectrophotometric Analysis and its Application in Ferrous Metallurgy.' *Analytica Chimica Acta*, 1952, vol. 6, Feb., pp. 157-89.

The author describes apparatus suitable for colorimetric analysis in monochromatic light. Instructions for operation are given, and its use is demonstrated by details of procedure for determination of a wide range of elements commonly present in steels and cast irons. Much of the technique employed by the author in the respective determinations is based on methods already described in the literature (to which due reference is given), but some original modifications are introduced. Two methods are described for estimation of nickel: the one is applicable to nickel contents of the order of 4 per cent.; the other is for use in determining very small amounts (up to 0·3 per cent.), and is applicable in presence of large proportions of cobalt.

Determination of Nickel in Coal Ash

L. W. GAMBLE and C. E. KLING: 'The Spectrographic Determination of Metallic Constituents in Petroleum Ash.' *Spectrochimica Acta*, 1952, vol. 4, No. 6, pp. 439-45.

Arc spectra of powdered samples on carbon electrodes and a grating spectrograph were used for estimation of iron, aluminium, silicon, manganese, magnesium, vanadium, nickel, sodium, and calcium, in petroleum ash. A spectroscopic buffer of nine times as much lithium carbonate as sample was used: the method was calibrated with synthetic standards. The wave-lengths used are tabulated, and the standard deviation of the precision is indicated.

Nickel-base Non-Ferrous Casting Alloys

See abstract on p. 150.

Hydrolysis of Nickel Chloride

K. H. GAYER and L. WOONTNER: 'Hydrolysis of Cobalt Chloride and Nickel Chloride at 25°C.' *Jnl. Amer. Chemical Soc.*, 1952, vol. 74, Mar. 20, pp. 1436-7.

The purpose of the investigation was to obtain data on the magnitude of the hydrolysis reactions of the halides of cobalt and of nickel. From the data reported it is concluded that $Ni(OH)_2$ and $Co(OH)_2$ are relatively strong bases. The results of this work confirm those obtained in solubility measurements on $Ni(OH)_2$ and $Co(OH)_2$.

Reduction of Nickel Oxide by Hydrogen

G. PARRAVANO: 'The Reduction of Nickel Oxide by Hydrogen.' *Jnl. Amer. Chemical Soc.*, 1952, vol. 74, Mar. 5, pp. 1194-8.

Reduction of nickel oxide by hydrogen was studied in the range 150°-350°C. and with initial hydrogen pressures of 200 to 500 mm. It was found that addition of foreign ions to nickel oxide affects both the rate and the activation energy for reduction. These effects were correlated with the change in the electronic properties of the oxide.

Adherence of Glass to Metals and Alloys

See abstract on p. 161.

ELECTRODEPOSITION AND OTHER COATING METHODS

Conservation of Nickel in the Plating Industry

A. K. GRAHAM: 'Conservation of Nickel in the Plating of Chemical Process Equipment.' *Plating*, 1952, vol. 39, Apr., pp. 369-70, 376.

The writer emphasizes the importance of strict adherence to minimum-coating-thickness specifications when plating chemical equipment, and discusses variables affecting the minimum thickness deposited. Quality of steel is classed as a factor of major significance, but one which, in the current condition of supply, is difficult to control. For this reason additional care must be exercized in the pre-plating cleaning cycle: an illustration of the effect of variations in cleaning treatment is given by means of data on (1) adhesion of nickel coatings of differing thicknesses on steel surfaces variously cleaned, and (2) the behaviour of these nickel coatings in the hot-water corrosion test.

In connexion with the suggestion that an undercoating of iron acts to reduce porosity in nickel coatings, test results are presented showing that a thin strike of iron (0·005-0·05 mil.: 0·13-1·3μ) under nickel deposits 3·0-4·0 mils (76-120μ) in thickness had no beneficial effect on behaviour in the hot-water test.

Scratch-wire brushing of a nickel-plated surface has also been proposed as a means of improving corrosion-resistance, on the assumption that burnishing so produced will flow the metal over minute capillary openings in the deposit. The present author gives information on tests showing the effect of brushing followed by application of a second nickel coating. These indicate that plated material so produced meets hot-water corrosion test specification requirements with a thinner coating of nickel than would be adequate without the intermediate scratch-brush treatment.

The above observations relate specifically to tests on flat panels on which a high degree of uniformity in metal distribution was obtained. It is emphasized, however, that on parts of complicated design minimum thickness must be ensured on the most inaccessible portion of the surface, necessitating, in some cases, heavy average thicknesses. For example, in plating large objects it may sometimes be necessary, in order to obtain minimum thickness of 3 mils (76μ) in recessed areas, to deposit an average thickness of 5-7 mils (127-178μ). Due to limitations on plating thus imposed by design considerations, attention has been directed to the possibility of electroplating flat sheet which is afterwards formed and fabricated. Difficulties inherent in this procedure are briefly indicated, and the writer expresses the opinion that plating prior to forming is unlikely to offer an easy solution to the problem of metal distribution and conservation of nickel.

Continuous electrolytic purification and prevention of contamination are primary factors in conservation, and correct maintenance of rack insulation is also a highly significant economic factor. A further important method of conserving nickel is by the use of anode scrap, e.g., by employing scrap anodes where short-length anodes are adequate, and by using baskets.

Supply and Use of Nickel: I.M.C. Report

See abstract on p. 146.

Structure of Coatings of Nickel Electrodeposited on Single Crystals of Iron

D. J. EVANS and M. R. HOPKINS: 'An Electron-Diffraction Investigation of the Structure of Electrodeposited Coatings on Iron Single Crystals.' *Inst. Metal Finishing, Advance Copy* 8, Apr., 1952, 10 pp.; *Jnl. Electrodepositors' Tech. Soc.*, 1952, vol. 28.

Earlier investigations on the crystal structure of electrodeposited coatings formed on various substrates have shown that the character of the deposit depends on both the nature of the substrate and the conditions obtaining in the plating bath. A note on some of the experimental results already published is given by the present authors. In the main, earlier work has been confined to metals of the cubic system, deposited on cubic substrates having simple planes parallel to the surface, and the general observation is made that the cube faces of the deposit and substrate are always parallel, although there is sometimes a relative rotation, so that the cube face diagonal of one is parallel to the cube edge of the other. The present paper describes results obtained when zinc (hexagonal close-packed), copper (face-centred cubic) and nickel (in the usual face-centred cubic and the less usual hexagonal close-packed form) are deposited, under various plating conditions, on electropolished single crystals of body-centred cubic iron having planes of high Miller indices parallel to the surface.

In the case of zinc the (0001) plane of the deposit was always parallel to the (110) plane of the iron. For nickel it was found that when the conditions are such that it is deposited in the close-packed hexagonal form, the relative crystallographic dispositions of deposit and substrate are exactly the same as in the case of zinc. Copper (face-centred cubic) and nickel in the face-centred cubic form were found to be deposited with their (111) planes parallel to the (110) plane of the iron. It is noted that the orientation of the deposit with respect to that of the substrate appears to be independent of the crystallographic disposition of the surface of the substrate. It is suggested that an electropolished surface should be regarded as a macroscopic concept, and that on an atomic scale parts of simple crystallographic planes are exposed in a plating bath. This would mean that in the plating experiments described in this paper the actual effect was to deposit some atoms on low index planes in the initial stages. It would then be expected that the lattice planes of substrate and deposit would always bear the same relation to one another.

The results obtained in this investigation emphasize the importance of the effect of composition of the plating solution on the structure of the deposit, since with some solutions only a polycrystalline deposit was observed, even under a variety of plating conditions.

Commercial Nickel Plating of Aluminium

A. W. WALLBANK: 'The Plating of Aluminium Articles as a Production Process.' *Inst. Metal Finishing, Advance Copy No.* 7, Apr., 1952, 9 pp.; *Jnl. Electrodepositors' Tech. Soc.*, 1952, vol. 28.

Problems inherent in the plating of aluminium-base materials are briefly reviewed, and reference is made to processes which have been proposed for obviating the difficulties encountered. Most of the methods used for electroplating aluminium depend either upon prior deposition of a metallic film, or upon anodizing followed by modification of the anodic film, to secure adhesion of the electrodeposit to the basis metal. The most popular of the immersion methods is that employing sodium zincate: conditions for its use have been studied by numerous investigators, and the anodizing method has also been the subject of technical and patent literature. Reference is directed to some of the major publications.

The present author, while conceding that both immersion and anodizing methods are capable, in the hands of experienced platers, of giving good results, points out that when considered as commercial processes both have severe limitations, which are briefly discussed.

A description is then given of the Vogt process, development of which in England began in 1929. This procedure is in line with modern views in using a preliminary coating of zinc, but, unlike the sodium zincate procedure, the zinc coating in the Vogt process is electrodeposited. The film is uniform and continuous, but is too thin to withstand exposure in a nickel-plating solution for further treatment. It is therefore reinforced by a thin superimposed coating of brass. Nickel is then deposited from a bath very low in chloride, and operated under conditions which yield a soft, unstressed deposit. The adhesion of the nickel is enhanced by stoving, and the plated article is then mopped and chromium plated by usual methods. Full details are given in this paper of the sequence of operations, from cleaning and etching, through to stoving.

A great advantage of the process is claimed to be its applicability for plating a wide range of aluminium alloys: only those containing more than 3 per cent. of magnesium cause any difficulty, and it is found possible, by means of special precautions in the cleaning stage, successfully to plate even alloys of that type.

The author urges that the Vogt process, which has been developed almost solely on an empirical basis, is worthy of detailed research, in order that its full potential value may be realized and that it may come to occupy, in the commercial plating world, the important place which, by its essential characteristics, it is qualified to take.

Nickel Plating as Undercoat to Silver

'Nickel Base for Silver Plating.' *Nickel Topics*, 1952, vol. 5, No. 3, p. 8.

In silver-plating of steel bearings the use of a nickel strike has been found essential, in order to obtain good adhesion of the silver to the steel. Both solutions shown below give satisfactory results.

	(1)
Nickel sulphate	40 oz./gal.
Nickel chloride	4-6 oz./gal.
Boric acid	1½-3 oz./gal.
pH (quinhydrone electrode)	2·0-3·0
Temperature	100°-110°F. 38°- 43°C.
Current density	20-30 amp./sq. ft.

	(2)
Nickel chloride	32 oz./gal.
Hydrochloric acid	11 fl. oz./gal.
Temperature	75°F. 24°C.
Current density	100-150 amp./sq. ft.

Plating time, when using either solution, may vary from one to three minutes. It is also desirable to use an anodic sulphuric-acid etch, in order to secure good adhesion between the steel and the nickel, and to give a silver strike after the nickel strike (prior to final silver-plating), in order to prevent formation of immersion deposits of silver.

Wear-Resistance of Electrodeposited Nickel

R. F. LEDFORD and E. A. DOMINIK: 'Comparative Wear Characteristics of Some Electrodeposited Metals.' *Plating*, 1952, vol. 39, Apr., pp. 360-5.

The authors present data on comparative wear-resistance of electrodeposited copper, nickel, chromium and iron. In view of the practical importance of wear-resistance of electrodeposited coatings for printing plates, the test for evaluation of the wearing quality of the respective metals was made on a machine used for determining the abrasiveness of printing inks. Mode of operation of the machine is illustrated. The

test panels were prepared in such a way as to ensure strict comparability; details are given.

Three copper, one chromium, one iron, and eight nickel baths were used. The nickel solutions were of eight basic types, including a Watts bath and other types of solution generally employed in the plating industry, and also baths of more specialized composition which have been proposed for use in the printing industry and for other applications in which hardness and/or wear-resistance are factors of particular importance. The influence of small amounts of impurities, on the wear-resistance of deposits made from some of these baths, was also investigated. In this connexion the effects of iron, copper, silver, tin, antimony, lead and zinc were studied. Results of the various tests are individually reported.

It is observed that some of the additions made to the nickel-plating baths appear to have exercized a considerable influence on wear-resistance. This was particularly true of a zinc addition and of small additions (0·1 g./L.) of copper. The authors emphasize, however, that they do not advocate the use of such additions without further investigation of their possible effects on the other qualities of the deposit. No correlation was found between brightness of the nickel deposits and their behaviour in the wear test. It is noted that the wear-test results obtained with chromium coatings varied according to the nature of the undercoat used. For example, a flash coating of chromium over nickel had a higher rating than chromium over copper. With heavier chromium coatings the influence of the undercoat was less pronounced.

Use of Nickel in Electrotyping

'Electrotyping in the Government Printing Office.' *G.P.O.-P.I.A. Joint Research Bull., Plate Series No.* 2. Obtainable from Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., U.S.A. Price 20 cents.
Extended abstract in *Plating Notes*, 1951, vol. 3, Dec., pp. 206-28.

This publication opens with notes on printing practice in general, as a background to a description of the place of electrotyping in this industry. The essential features of typographic, intaglio and planographic printing processes are described, with illustrations.

Methods used in electrotyping are then dealt with in detail, particulars being given of operations involved in making the mould conductive, depositing the copper, depositing the thin hard layer of nickel which serves as the printing surface, depositing iron (used under war conditions in partial replacement of nickel and copper), preparation of copper or nickel for backing, backing-up, and deposition of chromium.

The Salt-Spray Test

'A Critical Look at Salt-Spray Tests.' Comments on article by F. L. LAQUE, *ibid.*, Feb., pp. 77-81 (*Nickel Bulletin*, 1952, vol. 25, No. 5, p. 129). *Materials and Methods*, 1952, vol. 35, Mar., pp. 77-91, 156-68 (even numbers only).

The comments, which have been obtained from a representative group of scientists, electroplaters and users of coated materials, differ widely in the views expressed on the value of the test. Some strongly support it, others condemn it as valueless, while still another group argues that, within limits, the method gives useful data. Almost all are in agreement that there is room for improvement in technique of testing and in defining the sphere of application of the results obtained by tests of resistance to salt spray. There is also general concurrence that the provocative article by LaQue has served a useful purpose in starting discussion, as a result of which the test may be modified to give more practically informative data.

Nickel vs. Cobalt Dips in Porcelain Enamelling

J. H. KEELER, P. K. CHU and H. M. DAVIS: 'On the Rôle of Nickel in Porcelain Enameling.' *Jnl. Amer. Ceramic Soc.*, 1952, vol. 35, Mar., pp. 72-5.

Following a brief introduction on the use of nickel and cobalt oxides and of the nickel-dip treatment in preparation of steel for enamelling, the authors give an account of tests made to determine the relative efficacy of coatings of nickel and of cobalt. Sand-blasted specimens of low-carbon steel sheet were used as base, and the transparent enamel frit employed had a composition similar to that of an ordinary commercial ground coat, but contained no adherence-promoting or colouring oxides.

Directly-enamelled specimens showed marked defects soon after removal from the enamelling furnace, and these increased in size and number on storage at room temperature. Enamel coatings on the same steel previously treated with a heavy nickel dip (15 minutes at 72°C. in 3 per cent. nickel ammonium sulphate solution) exhibited no delayed defects. A series of comparative tests, on nickel-dipped and directly coated enamelled specimens, indicated that the presence of nickel at the steel-enamel interface promotes rapid ageing. It is concluded that the nickel, presumably acting in the oxide form, promotes rapid transfer of hydrogen from the steel to the enamel while the fired material is cooling, thus reducing the amount of hydrogen available for the generation of delayed enamel defects. Specimens treated, prior to enamelling, with an electrodeposited film of cobalt did not show the same acceleration of ageing in comparison with directly-enamelled specimens, indicating that cobalt coating is not so beneficial in this connexion as nickel dipping.

It has been observed in industrial enamelling practice that nickel-dipped steel sheet which has been unsatisfactorily enamelled and subsequently de-enamelled may not exhibit defects when re-enamelled without repetition of the nickel flash. Laboratory experiments reported by the present authors confirmed that the beneficial influence of a single nickel dip persists through repeated re-enamelling. Electrographic tests showed the presence of retained nickel on singly nickel-dipped panels even after five re-enamellings with intervening sand-blasting treatments. Progressive diffusion of the nickel into the steel during repeated firings is apparently sufficient to provide a residual nickel effect at each freshly exposed surface.

NON-FERROUS ALLOYS

Nickel-base Non-Ferrous Casting Alloys

J. S. VANICK: 'Nickel-base Non-Ferrous Castings.' *Foundry*, 1952, vol. 80, Apr., pp. 94-7, 257-8, 260-1.

This article gives a summary of data on the composition, production, and properties of cast nickel and nickel-base alloys of the following types: nickel alloyed with small amounts of tin or silicon; Monel (normal, 'H', and 'S' grades); Inconel; Hastelloy and Langalloy alloys (nickel-molybdenum-base and nickel-silicon-copper types); Chlorimet alloys (nickel-molybdenum and nickel-molybdenum-chromium types); Colmonoy (nickel-chromium-boron); Durco 10 (complex nickel-chromium containing small amounts of copper, iron and molybdenum); Waukesha 50 (nickel-chromium-iron) and Waukesha 23 (high-nickel alloy containing copper, tin and lead). Particular attention is directed to the valuable combinations of engineering properties offered by the respective alloys, which include high mechanical strength and hardness (a useful degree of which is retained in some of the alloys at elevated temperatures), resistance to galling (seizure), and corrosion-resisting properties. Mention is also made of the fact that the Monel and other nickel alloys which do not contain an excess of precipitation-hardening elements and which are characterized by a high order of toughness, are, in general, unaffected by changes in temperature down into the subnormal freezing-temperature regions. The wide range of applications for which the various nickel-base casting alloys have proved their suitability is indicated by a list of parts in which they are currently used in many branches of the engineering industries.

Supply and Use of Nickel: I.M.C. Report

See abstract on p. 146.

Welding of Nickel and Nickel Alloys

E. FUCHS and H. BRADLEY: 'Welding Practice. Vol. III. Welding of Non-Ferrous Metals.'

Published by Butterworths Scientific Publications, in association with Imperial Chemical Industries, Ltd., 1952, 180 pp., plus index. Price 22/6.

This series, prepared by past and present members of the Welding Panel of Imperial Chemical Industries, Ltd., is divided into three parts. Aspects of the subject which are common to all applications of welding are dealt with in volume I, entitled 'Welding Methods and Tests' (price 17/6): this is to be regarded as complementary to the other two volumes, which cover, respectively, specific problems arising in the welding of ferrous and of non-ferrous materials. (Volume II, on ferrous metals, is not yet published.)

The various chapters dealing with the welding of the individual non-ferrous metal groups are arranged on a uniform basis, comprising a discussion of metallurgical factors affecting weldability and technique of welding the respective materials, recommendations to designers of welded parts, welding materials for use with various types of metal and alloy, workshop practice, and special applications. A glossary of welding terms (common to the whole series) is included in each volume.

The non-ferrous volume contains chapters on welding of copper, brasses and bronzes, nickel and nickel-rich alloys (also nickel-clad steel), silver, aluminium and aluminium alloys, lead. The final chapter deals with brazing of both ferrous and non-ferrous metals.

Monel in Gas Water Heaters: Condensation Studies

AMER. GAS ASSOCN. LABORATORIES: 'Condensation in Gas Water Heaters.' *Research Bull.* 58, Oct., 1950; 45 pp.

Interference in operation of heaters due to condensation is not a universal problem in the gas industry, but occurs sufficiently frequently to warrant examination of causes and methods for prevention. The American Gas Association therefore sponsored a research in which, following a review of the literature, a fundamental study was made of the effect, on condensation, of surfaces of metals and alloys used in construction of water heaters. Determinations were made of the rate of condensate formation on metal surfaces maintained at constant temperature, rate of transfer of heat to water, and rate of disappearance of condensate from metal surfaces backed by still water. Copper, galvanized iron, and Monel were included in the various experiments, using, in each case, specimens in various surface conditions, e.g., clean bare, rusted, scaled, etc. Results obtained were used as a basis for recommendations on modifications of design and other means for eliminating excessive condensation or minimizing its effects.

The data presented indicate that for all practical purposes the type of metal (among the varieties usually employed), and the emissivity of its surface, have no effect on the rate of condensation of water vapour from flue gases. The presence of sulphur in a fuel gas, however, raises the dew-point temperature of the flue gases and increases the rate of formation of condensate on metal surfaces. It is shown, also, that rate of transferring heat to water and rate of elimination of condensate are greater for dropwise condensation than for filmwise condensation. Heat transfer and rate of condensate formation are increased by changing a metal surface from a reflecting condition to a back-body condition. Increasing thermal resistance, e.g., by scale formation on the water side of a metal, results in decrease in heat transfer, but causes no significant change in rate of disappearance of the condensate.

Flow Lines in Cold-worked Nickel Silver

R. ERGANG and S. WELZ: 'The Occurrence and Prevention of Flow Lines in Nickel Silver and Brass.' *Zeitsch. für Metallkunde*, 1952, vol. 43, Feb., pp. 45-8.

Flow lines (illustrated in the paper) have been observed, from time to time, on objects of nickel silver and 63 per cent. brass which have been subjected to only a small degree of cold work. The phenomenon is associated with a sharply marked yield on the stress-strain curve of the materials susceptible to the effect, similar to the 'knick' found in testing of steel. This paper reports an investigation of the nature of the

effect, and of practical means which may be adopted to prevent its occurrence. The nickel silver alloys studied contained, respectively, copper 63·4, nickel 17·6, manganese 0·29, per cent., balance zinc, and copper 62·4, nickel 12·6, manganese 0·25 per cent., balance zinc: the brass was of the 63 per cent. copper grade. The phenomenon reported was observed only in annealed and extensively recrystallized sheet of an average grain size of 0·07-0·09 mm.

Results of various cold-working and annealing experiments showed that formation of flow figures can be prevented by a mild form of cold working beyond the yield point, e.g., by rolling to 2 per cent. reduction or treatment in a sheet-straightening machine. Annealing at a temperature not below 500°C., followed by water quenching, also has an inhibiting effect, and coarse-grained material is not subject to the defect. Alloys which have undergone the preventive treatments again become susceptible to flow-line formation after prolonged heating at a temperature of at least 100°C. Storage for 6 months at room temperature did not, however, result in re-appearance of the yield-point and flow-line phenomena in nickel silver specimens which had been adequately cold-worked or annealed at 600°C. and quenched.

Adherence of Glass to Metals and Alloys

See abstract on p. 161.

Analysis of Nickel Silver

J. H. VAN DER MEULEN: 'Analysis of New Silver.' *Chemisch Weekblad*, 1951, vol. 47, July 28, pp. 560-1.

In the method recommended the alloy is dissolved in 5*N* hydrochloric acid to which 30 per cent. hydrogen peroxide is gradually added, the excess being expelled by carbon dioxide. Alternatively, the oxidizing agent may be 5*N* nitric acid, excess of acid being neutralized with potassium hydroxide. Copper is determined iodimetrically. It is removed by treatment with *N* potassium iodide and sulphur dioxide, excess of sulphur dioxide being driven off. Nickel is then determined with alcoholic dimethylglyoxime solution. After filtration of the nickel glyoxime precipitate sodium hydroxide is added to the filtrate, in which zinc is finally determined iodimetrically. It is claimed that the method ensures separation of the component elements in a pure state by avoiding addition, to the reaction mixture, of detrimental reagents.

NICKEL-IRON ALLOYS

The Iron-Nickel-Nitrogen System

W. SCHLÜTER: 'The Iron-Nickel-Nitrogen System.' *Stahl und Eisen*, 1952, vol. 72, Feb. 14, pp. 197-8. (Based on dissertation submitted to the University of Heidelberg, by H. MÜHLBERG, in 1948.)

The alloys used in this investigation were made by nitriding fine particles of nickel-iron alloys of various compositions which had been melted under hydrogen. At temperatures below 600°C. the nitriding treatment was of 24 hours' duration; at higher temperatures treatment was for only 12 hours. The specimens so treated were rapidly cooled in ammonia, to room temperature, and the nitrogen content was determined by measurement of increase in weight. The ternary alloys were then examined by X-ray methods.

It was found that variation in temperature of nitriding treatment had an important effect: for each composition of nickel-iron alloy there was a temperature range in which maximum nitrogen-absorption occurred. Rising nickel content caused a sharp fall in absorption.

It was observed that in iron-nickel-nitrogen alloys produced from nickel-rich alloys (down to about 30 per cent. of nickel) those containing less than about 4 per cent. of nitrogen consisted of two phases: (1) cubic face-centred γ iron-nickel solid solution containing dissolved nitrogen, and (2) cubic-face-centred crystals of a nitride phase corresponding to the γ' phase (Fe_4N) in the binary iron-nitrogen system, but having part of the iron replaced by nickel. Alloys in which the nitrogen content is above 4 per cent. consist solely of the nitride phase. At temperatures below 500°C. and with nitrogen contents of less than 3 per cent., ternary alloys prepared from nickel-iron alloys containing less than 30 per cent. nickel exhibited, in addition to the two cubic face-centred phases, cubic space-centred α iron-nickel solid solution containing dissolved nitrogen, and at temperatures above 500° and with nitrogen contents above 5 per cent. a hexagonal nitride phase occurred in these alloys, corresponding to the ε phase (Fe_2N) in the iron-nitrogen system. No equilibrium condition was, however, established for these alloys, since on annealing the hexagonal phase disappeared, unless the nitrogen content was above 6 per cent.

On annealing in vacuo the nitrides decomposed: in nitrogen-rich alloys this effect occurred as low as 360°C.; with decrease in nickel the temperature of decomposition rose to 500°C.; above that temperature none of the alloys were stable.

The tests showed that the lattice constants of the γ' nitride phase increased with rise in temperature of nitriding, reaching a maximum at 800°C. It was also observed that enlargement of the lattice constant of the γ' nitride phase was associated with rise in values for maximum nitrogen absorption, but the maxima for nitrogen absorption given in graphs for temperature vs. nitrogen absorption did not occur at the same position as the maxima for the lattice constant. The observation of this discrepancy led to development of a method by which nitrogen absorption could be considerably increased. Iron-nitrogen alloys were treated for 12 hours, in a stream of ammonia, at temperatures between 600° and 800°C. which had been found to be associated with maximum expansion of lattice constant. After such treatment the alloys were quenched to room temperature and subsequently re-treated in a stream of ammonia at temperatures between 435° and 490°C. which had been experimentally established as being most favourable (although not corresponding to those giving maximum nitrogen absorption under single-nitriding conditions). This double treatment considerably increased the amount of nitrogen absorbed: in high-nickel alloys absorption was several times that

obtained by single treatment. The results are graphically illustrated, in comparison with those obtained in the earlier single-treatment experiments.

The investigation led to the following conclusions:—

In the γ' phase (Fe_4N) of the iron-nitrogen system the iron atoms can be replaced, to a large extent, by nickel. From the γ' region of the binary system there extends far into the ternary system a γ' phase region, which runs approximately parallel to the iron-nickel side of the ternary diagram but is closed at lower iron contents, since no nickel nitride (Ni_4N) is formed. In the ε phase (Fe_2N) of the binary system also part of the iron atoms can be replaced by nickel, but the ε phase region does not extend so far into the ternary region, only indeed to iron contents of about 26 per cent. The limit of the ε-phase region in relation to the ($\gamma'+\varepsilon$) region is shifted as the nickel increases, to higher nitrogen contents.

The temperature of the eutectoid decomposition of the γ solid solution in the binary iron-nitrogen system is reduced by nickel: with nickel contents above about 30 per cent. in the original nickel-iron alloys the region in the ternary alloys which corresponds to the ($\gamma+\gamma'$) region in the iron-nitrogen systems extends to about room temperature, and runs, like the γ' region, parallel to the iron-nickel side of the ternary diagram.

The Iron-Nickel-Aluminium System

A. J. BRADLEY: 'Microscopical Studies on the Iron-Nickel-Aluminium System. Part III. Transformations of the β and β' Phases.' *Jnl. Iron and Steel Inst.*, 1952, vol. 171, May, pp. 41-7.

Photomicrographs presented in this paper illustrate the course of the reactions taking place when the body-centred cubic structures of the iron-nickel-aluminium system break up during cooling. Decomposition may take place either by the deposition of the face-centred cubic lattice, or by the splitting of the body-centred cubic lattice into two phases, one being ordered, the other disordered. The former process is predominant at higher temperatures, the latter at lower temperatures.

There is a maximum tendency for β, the disordered phase, to deposit α, the face-centred cubic phase, at about 1150°C., giving the highly irregular $\beta+\alpha$ structures. Under certain circumstances the whole of the precipitated α may redissolve before any of the ordered β' phase is formed from the disordered β lattice. In other cases the ordered phase is precipitated before the α phase redissolves, and a three-phase alloy of the type $\beta+\alpha+\beta'$ is formed. Similar effects occur in the decomposition of the β' phase. The α phase tends to redissolve, so that the $\beta'+\alpha+\beta$ structures are superseded by $\beta'+\beta$ structures at lower temperatures.

It is shown that high coercivity is exclusively connected with the incipient breakdown of the non-magnetic NiAl-rich ordered β' structure, which must remain predominant in order to form a continuous matrix. Under the most favourable circumstances this precipitate consists entirely of the lamellar ferromagnetic iron-rich β phase.

Fe_2NiAl is often quoted as a special case of a permanent-magnet alloy. Here the ordered body-centred cubic lattice may deposit the disordered phase without any face-centred cubic phase being formed. Small traces of the α phase may be ascribed to out-of-equilibrium processes.

Nickel-Zinc Ferrites

K. F. NIESSEN: 'Curie Temperature of Nickel-Zinc Ferrites as a Function of the Nickel-Zinc Ratio.' *Physica*, 1951, vol. 17, Nov.-Dec., pp. 1033-49.

In a series of mixed crystals of nickel ferrite and zinc ferrite, the ratio of the Curie temperature to that of zinc-free ferrite can be calculated by means of a generalization of Néel's extension of the Weiss theory, to ferrites. Observations on relation of Curie temperature to composition leads to the prediction that zinc ferrite is antiferromagnetic.

Nickel Alloys in Glass-to-Metal Seals

P. WHIBLEY: 'Glass Tube Technology. 1. Glass-to-Metal Seals.' *Ohio State Univ., Engineering Experiment Station News*, 1951, vol. 23, Dec., pp. 48-51, 55.

A general review article, describing various forms of seal (with examples of matched and unmatched types), the metallic materials used in sealing, the compositions of the oxides formed during making of the seal and those present in the finished seal, and the thermal coefficients of expansion of glasses and metals used. Stresses between glass and metal components of the seal are discussed, with diagrams illustrating the conditions in various types of seal, and methods used for measurement of stress.

Supply and Use of Nickel: I.M.C. Report

See abstract on p. 146.

CAST IRON

Cerium Treatment for Neutralization of Subversive Elements in Production of S.G. Iron

H. MORROGH: 'The Harmful Influence of Some Residual Elements in Magnesium-treated Nodular Cast Irons and their Neutralization by Cerium.' *Brit. Cast Iron Research Assocn. Jnl. of Research and Development*, 1952, vol. 4, Apr., pp. 292-314.

The magnesium process for production of spheroidal-graphite cast iron is applicable to cast irons of a wide range of composition with respect to carbon, silicon, manganese, phosphorus, sulphur and nickel contents, but it has been found that certain other elements, liable to be present in small amounts in some types of pig iron, have an inhibiting effect on response to magnesium treatment. MILLIS, GAGNEBIN and PILLING (*U.S. Pat.* 2,485,760) listed tin, lead, antimony, bismuth, arsenic, selenium, and tellurium: they also pointed out that copper in large amounts inhibits formation of spheroidal graphite, but that the amount of copper

which can be tolerated is larger in nickel-containing than in nickel-free irons.

The present writer, who has been closely associated with the development of the cerium treatment for cast iron, states that, in his experience, 'irons substantially free from subversive elements, when appropriately treated with magnesium and inoculated, can give completely nodular graphite structures even in very large section'. The investigation which he reports in the present paper was concerned with the harmful effects of titanium, lead, antimony, bismuth, aluminium, copper, tin, and arsenic, in magnesium-treated iron. Experimental results are recorded to show the extent to which the respective elements interfere, and the beneficial influence of cerium additions in ensuring response to magnesium treatment.

It is shown that even very small quantities of titanium, lead, antimony and bismuth, either singly or in combination, can prevent formation of spheroidal graphite by magnesium treatment. Aluminium, in somewhat larger amounts than those likely to occur in raw materials, can also have a subversive influence. In the absence of subversive elements, copper can be tolerated in amounts up to about 3 per cent., but copper appears to make the irons more sensitive to the deleterious effect of other interferants. Tin, up to at least 0·13 per cent., and arsenic up to 0·09 per cent., appear to have no influence on production of spheroidal graphite in magnesium-treated irons, but these elements have a profound influence in increasing the stability of pearlite.

The experiments reported in the paper demonstrate that small additions of cerium are capable of neutralizing the harmful effects of titanium, lead, bismuth, antimony, aluminium and copper. A residual cerium content of 0·005 per cent. is usually ample, and in many cases an even smaller amount is sufficient. It is thus possible to use, for the magnesium treatment, raw materials which have previously been considered unsuitable as base irons.

The cerium may be added before, at the same time as, or after, the magnesium addition. Mischmetall is considered to be the most convenient source of cerium, but any other cerium-containing alloy can be used, e.g., nickel-magnesium-cerium, magnesium-cerium, etc.; the cerium may be added simultaneously with, or in combination with, the inoculant. If cerium is added before or together with the magnesium-containing material it appears to delay removal of sulphur, resulting in production of irons of abnormally high sulphur content. This effect can be obviated by adding the cerium after the magnesium.

Influence of Phosphorus on Hot-Tearing Resistance of Nickel-Alloy Cast Iron

J. C. HAMAKER and W. P. WOOD: ' Influence of Phosphorus on Hot-Tear Resistance of Plain and Alloy Gray Iron.' *Amer. Foundrymen's Soc., Preprint* 52-30, May, 1952; 10 pp.

Hot-tearing is an important problem in the foundry industry, especially in connexion with the production of heavy castings, where very low carbon equivalents are necessary in order to obtain the desired properties in heavy sections. Reduction in susceptibility to hot-tearing resolves itself mainly into increasing the strength of the iron shortly after solidification, and, due to the low melting point of the phosphide eutectic and its tendency to form a liquid network round the iron-carbon eutectic cells, phosphorus content would be expected to exercize a profound influence on the strength of grey iron in this range of temperature. This presumption has been confirmed by industrial experience. It has also been observed that certain combinations of alloy additions may increase the tendency to hot-tear formation, although the chill and graphitic-carbon content remain essentially constant. A further investigation of the properties of phosphide eutectic showed that both molybdenum and chromium segregate strongly to the liquid phosphide, considerably increasing its volume and, in the case of molybdenum, lowering its freezing point.

Based on the above knowledge, an investigation was undertaken by the authors to determine the influence of phosphorus and of certain alloy elements on the strength of a selected base iron, at temperatures within a few hundred degrees of the iron-carbon eutectic. A detailed and well illustrated description is given of the mould design used for direct-cooling high-temperature tensile tests, of the typical casting, experimental test set-up, and technique of testing. The procedure developed provided a means of measuring the properties of the irons shortly after solidification, under actual hot-tearing conditions. Forty-four tests were made, at temperatures of 2050°-1650°F. (1120°-898°C.). The base iron used contained total carbon 2·90, silicon 2·10, per cent. The alloy irons produced from this base contained, singly, 2 per cent. nickel, 1 per cent. chromium, 1 or 0·54 per cent. molybdenum, and 1·50 per cent. nickel with 0·50 per cent. molybdenum. Phosphorus levels used were 0·04, 0·16 and 0·25 per cent.

The results show that irons containing 0·04-0·16 per cent. phosphorus were most susceptible to hot-tearing in the range 1900°-1800°F. (1035°-980°C.), while 0·25 per cent. phosphorus irons were susceptible over the extended range of 1900°-1700°F. (1035°-925°C.). At these temperatures the various compositions possessed tensile strengths of 1600-3500 p.s.i., thus indicating the magnitude of hindered contraction stresses necessary for formation of hot tears.

Due to the presence of liquid phosphide eutectic, the ultimate-strength values in the hot-tearing range varied consistently with phosphorus and alloy content. The hot-tearing tendency of plain grey irons did not increase appreciably until the phosphorus content exceeded 0·16 per cent., whereas the alloy irons exhibited marked reductions of strength when the phosphorus was increased from 0·04 to 0·07 per cent., and lost over 30 per cent. of their original strength at 0·16 per cent. phosphorus. Molybdenum and chromium additions sharply reduced the hot strength of plain iron at phosphorus levels as low as 0·10 per cent., by segregating to the phosphide eutectic, to increase its volume. Nickel also caused some reduction in hot strength at phosphorus levels above 0·12 per cent.

Internal Porosity in Alloy Iron Castings

J. C. HAMAKER, W. P. WOOD and F. B. ROTE: 'Internal Porosity in Gray Iron Castings.' *Amer. Foundrymen's Soc., Preprint* 52-53, May, 1952; 27 pp.

Industrial and laboratory studies, carried out by various investigators, have shown that internal porosity in iron castings differs distinctly from other forms of unsoundness. It has been found that although voids due to internal unsoundness have a well-defined dendritic structure typical of shrinkage, they cannot be eliminated by improvements in gating and risering which would prevent shrinkage or piping due to iron-carbon eutectic contraction. Further studies indicated that internal porosity appears when the phosphorus content of the iron exceeds a definite level, and that it is magnified by some alloy additions or by build-up of alloy residuals in returned scrap. Carbon and silicon contents, over wide ranges, are apparently without effect, although very-low-carbon irons (below 2·90 per cent.) have shown lessened tendency to internal porosity.

The present paper reports investigation of the mechanism of void formation, and the influence of composition on occurrence of the defect. The basis compositions of iron chosen were those normally used in the production of automotive castings: total carbon 3·00-3·40, silicon 2·10-2·40, manganese 0·75, sulphur 0·10, per cent. These irons were modified by single and combined additions of nickel up to 2·0, molybdenum up to 1·0, and chromium up to 1·0, per cent.: the phosphorus content was varied over the range 0·04-0·30 per cent. A detailed and well illustrated account is given of the 4-in. unfed cube casting and the precision balance used for determination of volume of voids, and of the observations made on the respective irons. From the results obtained, the following conclusions are drawn:

Visible internal porosity tends to appear in unalloyed grey iron castings when the phosphorus content exceeds about 0·25 per cent. Higher phosphorus increases the size of the spongy regions; reduction to 0·13 per cent. phosphorus is associated with progressively decreasing quantities of microporosity. Quantitative data indicate that this porosity is produced by the liquid and solidification contractions of the pseudo-binary phosphide-graphite eutectic, which forms a liquid network in the iron when the base phosphorus exceeds about 0·08 per cent., and solidifies at 1753°F. (955°C.).

Molybdenum and chromium additions to grey iron sharply reduce the critical phosphorus content required for formation of visible porosity, and subsequently increase the magnitude of the voids at a given phosphorus level. Combined chromium-molybdenum additions may produce visible voids at phosphorus contents as low as 0·06 per cent.

Straight nickel additions reduce porosity in plain grey irons to some extent, but balancing additions of nickel to irons containing molybdenum and/or chromium have little or no effect on their tendency to shrinkage. Unlike chromium and molybdenum, nickel shows no tendency to segregation in the phosphide eutectic.

In presence of 2·0 per cent. nickel the solidification contraction of the plain phosphide eutectic is changed into expansion, with resulting reduction in tendency to void formation, but in irons containing chromium or molybdenum the nickel in the eutectic is insufficient to balance the segregated amounts of the other alloys, and is ineffective in preventing the high contraction produced by the carbide form of solidification. The change from the graphite to the carbide form of phosphide eutectic solidification was found to occur in the slowly-cooled 4-in. cubes at about 0·50 per cent. molybdenum or chromium, and it is considered that the change might be expected to take place at lower alloy levels in lighter commercial castings, due to the more rapid rate of cooling.

Production of Ni-Hard Grinding Balls

'Ball Castings are not Solid.' *Foundry*, 1952, vol. 80, May, p. 172.

In the Questions and Answers section of this journal a foundry raises problems associated with production of sound grinding balls in cast iron containing nickel 4, chromium 1·5, per cent. (Ni-Hard). In reply, recommendations are made, with a dimensioned sketch showing gating procedure designed to minimize shrinkage and ensure dense castings.

Properties of Heat-Resisting Cast Irons

M. M. HALLETT: 'Tests on Heat-Resisting Cast Irons.' *Jnl. Iron and Steel Inst.*, 1952, vol. 170, Apr., pp. 321-9.

Comparison, on a quantitative basis, of data on heat-resisting cast irons previously published by various investigators is difficult, due to the different experimental methods which have been employed in the respective tests. The study reported in the present paper was specifically designed to compare, on the same basis, all the usual heat-resisting irons, in order to provide accurate information which could be used in selecting the most suitable material for any given set of service conditions. The irons tested (see table on p. 155) ranged from a low-silicon hematite iron, through a low-nickel-chromium type and high-silicon iron, to high-nickel and high-chromium grades. The Ni-Resist and Nicrosilal irons were studied at two chromium levels (2½ and 5 per cent.), and the high-chromium ferritic irons at 16 and 33 per cent. chromium. An experimental iron containing an addition of 10 per cent. of nickel to the 33 per cent. chromium type was tested to determine the influence of the nickel addition on the toughness of the iron.

The laboratory tests made comprised:—

(1) Comparison of scaling in air, at 750°, 850°, 950° and 1050°C., exposure being, at each temperature, for 18, 48, 120 and 240 hours.
(2) Growth tests after exposure at the same temperatures, for 18, 50, 120 and 240 hours.
(3) Examination of microstructure of specimens after heating for 120 hours at the four temperatures.
(4) Scaling tests in mildly oxidizing sulphurous atmospheres.

Analysis of Experimental Materials

Material	T.C. %	Si %	Mn %	P %	Ni %	Cr %	Cu %
S.S.M.P.	2·98	1·14	1·07	0·18	—	—	—
A.P.	3·45	1·64	1·03	0·15	1·18	0·92	—
Silal	1·89	5·70	0·96	0·16	Nil	0·05	—
Ni-Resist	2·74	1·93	0·89	0·04	14·62	2·11	7·16
Ni-Resist (5 Cr) ..	2·85	1·85	0·83	—	14·38	4·84	7·36
Nicrosilal	1·78	4·63	0·91	0·10	22·46	2·52	—
Nicrosilal (5 Cr) ..	2·10	4·90	0·89	0·05	22·79	4·63	—
Enduron	2·14	1·54	1·56	—	0·20	16·60	—
33 Cr	1·28	1·17	0·75	—	0·24	33·03	—
30 Cr, 10 Ni ..	1·12	1·78	0·57	—	9·36	29·62	—

(5) Determination of sensitivity to cracking due to alternations of temperature.

Confirmatory service tests were made on a series of furnace base plates and covers, cast from the same ladles of metal as those used for the scaling-test bars. Only the irons which had proved, in laboratory tests, to have a good degree of heat-resistance were included in this series, viz., Ni-Resist of high chromium content, both types of Nicrosilal, and the various high-chromium types of iron.

The experimental data are recorded in considerable detail, and the illustrations to the paper include many photomicrographs showing the structure of typical specimens and scaling effects. The results of the laboratory tests demonstrate that small alloy additions improve scaling-resistance at relatively low temperatures: silicon is particularly effective in reducing oxidation at temperatures up to about 900°C., but above this point its efficacy drops appreciably. Both laboratory and service tests indicated good resistance by high-chromium cast-irons, up to the highest temperature used. These irons appear to be less prone to cracking than would be anticipated, provided that the sections exposed at high temperatures are sufficiently thin to prevent the occurrence of thermal stresses. Particular attention is directed to certain oxidation phenomena observed in Ni-Resist and Nicrosilal irons.

S.G. Iron in Road-Roller Parts

'Road Roller Parts Now Made of Ductile Iron.' *Nickel Topics*, 1952, vol. 5, No. 3, pp. 1, 3.

It is reported that Littleford Bros., Inc., of Cincinnati, Ohio, now specify magnesium-treated cast iron for several important parts in their combined trailer-roller machine used in street-maintenance and other road work. The ring gear (which is one of the parts made in the new cast iron) replaces heat-treated cast steel, which failed badly due to wear: ordinary cast iron, as a replacement for steel, had also proved unsatisfactory, due to high wear and tooth breakage. Swivel-pin housings, brake-lever brackets and axle supports are other components for which spheroidal-graphite cast iron has been successfully introduced. It is also specified for ring gears in a roller of larger size made by the same firm.

Ni-Resist Piston Inserts

H. G. BRAENDEL: 'Ring, Piston and Cylinder Assembly.' *Soc. Automotive Engineers, Preprint, Jan.*, 1952; 10 pp.

The author discusses some of the major problems associated with the operation of the ring, piston and cylinder assembly of heavy commercial engines, and the measures currently used to solve them. The most serious condition observed recently in some engines having aluminium pistons is excessive wear of the top groove and ring, leading ultimately to the breakage of both the ring and the top land. It is not certain whether this trouble is due to the fuel, the lubricant, or the operating conditions, but a successful remedy has been found in the use of a Ni-Resist piston insert in which the top groove is machined.

Nickel-Alloy Cast Iron Pots for Melting Aluminium

'Melting Kettles of Nickel Iron Last Longer.' *Nickel Topics*, 1952, vol. 5, No. 3, p. 7.

Brief note, reporting successful experience with melting pots of cast iron containing nickel 1·00-1·25 per cent. It is stated that pots of this material are widely employed for melting various types of non-ferrous metals, and specific reference is made to satisfactory use in melting aluminium, in which application the alloy pots replace refractory non-metallic materials, giving lessened susceptibility to breakage.

Supply and Use of Nickel: I.M.C. Report

See abstract on p. 146.

Nickel-containing Materials in Water Filters

See abstract on p. 162.

CONSTRUCTIONAL STEELS

Data Sheets on Nickel-Alloy Steels

INTERNATIONAL NICKEL CO., INC.:
'Nickel Steels, Types 2300-2500 Series.'* *Publn. NS*-4.
'Nickel-Chromium Steels, Types 3200, 3300, 3400 Series and Krupp Steel.'* *Publn. NS*-5.
'Nickel-Molybdenum Steels, Types 4600 and 4800 Series.'* *Publn NS*-6.
Published 1951.

These sheets contain comprehensive information on composition, treatment and properties of the respective grades of nickel-containing steels, together with typical isothermal-transformation diagrams.

U.S. 'Conservation' Steels

'New Steel Compositions to Conserve Critical Alloying Elements.' *Materials and Methods*, 1952, vol. 35, Mar., p. 121.

Lists supplementing those published *ibid.*, Oct., 1951, pp. 135-37.

Details are given in the tables which appear on p. 157, opposite.

Determination of Molybdenum in Iron and Low-Alloy Steels

BRIT. IRON AND STEEL RESEARCH ASSOCN.: METHODS OF ANALYSIS COMMITTEE: 'Determination of Molybdenum in Iron and Low-Alloy Steels containing up to 0·5 per cent. of Tungsten.' *Jnl. Iron and Steel Inst.*, 1952, vol. 171, May, pp. 75-80.

The method described (for estimation of molybdenum 0·2-2·0 per cent.) is based on a preliminary separation of the molybdenum from iron and from most of the other common alloying elements, as the α-benzoinoxime complex. The behaviour of tungsten in the reaction was studied and a method for overcoming the interference of that element, depending on precipitation of molybdenum trisulphide in the presence of tartrate ions, is suggested. Complete precipitation of molybdenum trisulphide can best be achieved by decomposition of an alkali thiomolybdate with dilute mineral acid.

Determination of Vanadium in Low-Alloy Nickel-containing Steels

BRIT. IRON AND STEEL RESEARCH ASSOCN.: METHODS OF ANALYSIS COMMITTEE: ' Determination of Vanadium in Carbon and Low-Alloy Steels and Irons. *Jnl. Iron and Steel Inst.*, 1952, vol. 171, May, pp. 81-91.

The report includes consideration of methods of preparing a suitable solution of the sample, and of methods applicable for estimation of small amounts of vanadium. Cupferron and mercury-cathode separation procedures were investigated and potentiometric end-point determination was examined. The method ultimately selected for recommendation as standard involves a direct titration finish: it is proposed that it be included in the B.S. series of analytical methods.

Full details of procedure are given and tables of results for vanadium estimations on typical carbon and low-alloy steels are tabulated.

Spectrophotometric Determination of Nickel in Steel

See abstract on p. 146.

Supply and Use of Nickel: I.M.C. Report

See abstract on p. 146.

Nickel-Molybdenum-Vanadium Steel Welding Electrodes

D. C. SMITH and W. G. RINEHART: 'Heat-Treating Properties of Low Hydrogen Electrode Weld Metals.' *Welding Jnl.*, 1952, vol. 31, Apr., pp. 296-305.

Knowledge of the effect of heat-treatment on weld metals is required in selecting correct electrodes for welding aircraft steels, alloy steel castings and high-tensile steels which have to be heat-treated after welding.

This paper reports a detailed study of the heat-treating characteristics of typical low-hydrogen-electrode compositions which have recently been developed, and of some of the more conventional electrode materials. It includes data on the influence of heat-treatment on welds made with the nickel-molybdenum-vanadium steel electrode developed, during the war, for use without pre-heat. (For fuller details of this electrode see *Jnl. Amer. Soc. Naval Engineers*, 1950, vol. 61, Aug., pp. 601-19; *Nickel Bulletin*, 1950, vol. 23, No. 12, pp. 213-14). With this type of electrode a wide range of mechanical properties can be obtained by varying the percentage composition: the present authors studied two variants only, those used to meet the latest U.S. military electrode specification, which calls for strength levels of 100,000 and 120,000 p.s.i. (44·65 and 53·6 tons per sq. in.). Comparison is made of the behaviour, under heat-treatment, of this type of material and of a molybdenum-manganese steel, also used successfully as an electrode for welding steels of high hardenability. The two types vary quite widely in their response to heat-treatment, and the detailed experimental results recorded in this paper lead the authors to the conclusion that 'the moly-manganese type is the better electrode for both strength and repair welding when the weldment is to be given a heat-treatment for increasing strength and hardness after welding. On the other hand, the nickel-molybdenum-vanadium type is to be preferred if the weldment is to be made with little or no pre-heat and no subsequent heat-treatment'. It is stated that experience, over several years of use of both types of electrode, shows that highly restrained weldments require from 150°-200°F. (65°-93°C.) more pre-heat for the molybdenum-manganese than for the nickel-molybdenum-vanadium steel type. Although the impact strength of the latter is reduced somewhat by treatment at the

* *We shall be pleased to supply a free copy of this publication.*

(*See abstract U.S. 'Conservation' Steels on p. 156*

Standard Steels

Grade	Chemical Composition Limits				
	C %	Mn %	Si %	Cr %	Mo %
4118	0·18-0·23	0·70-0·90	0·20-0·35	0·40-0·60	0·08-0·15
5155	0·50-0·60	0·70-0·90	0·20-0·35	0·70-0·90	—

New Steels Developed to Conserve Nickel

(Intended for oil-well drilling equipment, e.g., rock bit cutters, as alternates for the 48xx grades.)

Grade	Chemical Composition Limits				
	C %	Mn %	Si %	Cr %	Mo %
T.S. 4613	0·10-0·15	0·45-0·65	0·20-0·35	1·65-2·00	0·25-0·35
T.S. 4618	0·15-0·20	0·45-0·65	0·20-0·35	1·65-2·00	0·25-0·35

Alternate Boron Steels

(The T.S. 43BV12 grade is intended as an alternate to the 33xx and 93xx grades for aircraft-engine parts: the T.S. 43BV14 grade as an alternate to the 33xx, 48xx and 93xx grades for heavy-duty truck parts, and T.S. 46B12 as an alternate to the 48xx grade for oil-well drilling equipment, such as rock-bit cutters.)

Grade	Chemical Composition Limits						
	C %	Mn %	Si %	Ni %	Cr %	Mo %	V %
T.S. 43BV12	0·08-0·13	0·75-1·00	0·20-0·40	1·65-2·00	0·40-0·60	0·20-0·30	0·03 min.
T.S. 43BV14	0·10-0·15	0·45-0·65	0·20-0·35	1·65-2·00	0·40-0·60	0·08-0·15	0·03 min.
T.S. 46B12	0·10-0·15	0·45-0·65	0·20-0·35	1·65-2·00	—	0·20-0·30	—

Tentative Standard Boron Steels

Grade	Chemical Composition Limits					
	C %	Mn %	Si %	Ni %	Cr %	Mo %
T.S. 14B35	0·33-0·38	0·75-1·00	0·20-0·35	—	—	—
T.S. 14B50	0·48-0·53	0·75-1·00	0·20-0·35	—	—	—
T.S. 40B37	0·37-0·40	0·70-0·90	0·20-0·35	—	—	0·08-0·15
T.S. 50B50	0·48-0·53	0·75-1·00	0·20-0·35	—	0·40-0·60	—
T.S. 50B60	0·55-0·65	0·75-1·00	0·20-0·35	—	0·40-0·60	—
T.S. 80B37	0·35-0·40	0·75-1·00	0·20-0·35	0·20-0·40	0·20-0·35	0·08-0·15
T.S. 81B40	0·38-0·43	0·75-1·00	0·20-0·35	0·20-0·80	0·35-0·55	0·08-0·15

NOTE 1: The boron steels can be expected to have 0·0005 per cent. minimum boron content.
NOTE 2: The phosphorus and sulphur limitations for each steel-making process are as follows: basic electric furnace, 0·025 max. per cent.; basic open hearth, 0·04 max. per cent.; acid electric furnace, 0·05 max. per cent.; and acid open hearth, 0·05 max. per cent.
NOTE 3: Minimum silicon limit for acid open-hearth or acid electric-furnace alloy steel is 0·15 per cent.
NOTE 4: Small quantities of certain elements are present in alloy steels which are not specified or required. These elements are considered as incidental and may be present in the following percentages: 0·35 copper, 0·25 nickel, 0·20 chromium and 0·06 molybdenum.
NOTE 5: These steels have been approved by the Iron and Steel Technical Committee of the Society of Automotive Engineers, Inc.

temperature generally used for stress-relief, the reduction on the 100,000 p.s.i. grade is not sufficient to impair the quality of the weldment. If the weldment is to be stress-relieved when the 120,000 p.s.i. grade of electrode is used, temperatures above 1250°F. (675°C.) should be used.

Pre-Heating Practice for Welding of Steels

A. B. TESMAN: 'Pre-Heating for Welding.' *Welding Jnl.*, 1952, vol. 31, Apr., pp. 306-13.

The paper opens with a consideration of the effects of pre-heating and the reasons for using this procedure when welding various types of steel. The effects, on steel structures, of temperature changes accompanying the welding operation are diagrammatically illustrated and the interrelation of metallurgical and mechanical considerations, as affecting susceptibility to cracking of welds, is emphasized. Five factors are of major importance in determining the ability of a steel to be welded without cracking: (1) composition of the steel, (2) rate of heating, (3) maximum temperature attained and length of time at temperature, (4) rate of cooling, and (5) hydrogen entrapment. The effects of these variables are individually considered.

With this background, the usefulness of pre-heating is discussed and factors which increase the need for such preliminary treatment are listed. A table gives recommended temperatures of pre-heating for use in welding steels of the following types: carbon, carbon-molybdenum, manganese, high-tensile low-alloy, nickel, medium nickel - chromium, molybdenum - bearing chromium and chromium-nickel, low- and medium chromium - molybdenum, plain high - chromium, and austenitic chromium-nickel.

Welding of Steel Castings: Recommended Procedure

'Recommended Practice for the Welding of Steel Castings.' *Welding Jnl.*, 1952, vol. 31, Apr., pp. 315-22.

As part of the research and development plan of the Steel Founders' Society of America, exhaustive study has been made of practices which have been recommended for welding of steel castings. The results are presented in the form of a reference manual of 40 pages, which forms a reliable basis for high-quality welding of such materials. The excerpt-report published in *Welding Journal* covers the high lights of the recommended practices given in the full publication.

Nickel-Molybdenum Steel Sling Chains

'Heat-Treated Nickel Alloy Steel Aids Sling Chain Users.' *Nickel Topics*, 1952, vol. 5, No. 3, p. 2.

The article reports the long and reliable service which is obtained in sling chains made from a nickel-molybdenum steel (120,000-140,000 p.s.i.: 53·5-62·5 tons per sq. in. tensile). The additional strength obtained by the use of the alloy steel makes it possible to use, with safety, $\frac{5}{8}$-in. chain in place of $\frac{3}{4}$-in. chain of wrought iron or mild steel. A further advantage of the nickel-molybdenum steel is that it is relatively free from susceptibility to grain growth on cold-working, and associated embrittlement.

Production of Nickel-Alloy Steel Airscrew Hubs

'Airscrew-Hub Manufacture. Part 1, Preliminary Metal-Removal Operations; Part 2, Machining the Driving Centre, and Assembly Operations.' *Aircraft Production*, 1952, vol. 14, Apr. and May, pp. 134-40, 176-82.

A detailed account is given of methods used by Rotol, Ltd., Gloucester, who are currently producing twelve basic types of airscrew hub. The hubs are of 65-ton steel containing carbon 0·22-0·28, silicon 0·3 max., manganese 0·35-0·65, nickel 2·75-3·5, chromium 1·0-1·4, molybdenum 0·65, per cent. Steel to S.69 (nickel 3-3½, carbon 0·3-0·4, per cent.) or D.T.D. 188A (low-manganese-molybdenum) is used for the driving centre.

HEAT- AND CORROSION-RESISTING ALLOYS

Nickel-Chromium-Cobalt and Nickel-Chromium Cobalt-Iron Alloys

W. D. MANLY and P. A. BECK: 'Survey of the Chromium-Cobalt-Nickel Phase Diagram at 1200°C.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 2602, Feb., 1952; 45 pp.

This report covers results obtained in the first stage of an investigation of the constitution of simple and complex chromium-cobalt-nickel alloys typical of those being developed for high-temperature service. For reasons which are discussed in the introduction, this general survey is to be restricted to observations at a single temperature, 1200°C. being chosen (1) because it lies in the range in which most of the commercial alloys are solution-treated and is therefore of immediate practical interest, and (2) because this temperature allows diffusion to proceed sufficiently fast to permit approach to equilibrium in reasonable annealing periods.

The survey of the chromium-cobalt-nickel phase diagram was made by means of microscopic and X-ray diffraction studies on 110 vacuum-melted alloys prepared from commercial metals of the highest purity available. It was found that at 1200°C. the following phases occur: (1) very extensive face-centred-cubic solid solutions, based on the binary cobalt-nickel solid solutions; (2) brittle sigma solid solutions, based on the chromium-cobalt sigma phase which is isomorphous with the iron-chromium sigma phase. In the sigma solid solutions well over half of the cobalt can be replaced by nickel with relatively little change in the chromium content. The diagram indicates that the sigma phase may co-exist with alpha of a nickel-cobalt ratio higher than 2. The brittleness of alloys consisting essentially of the body-centred-cubic phase was correlated with the plate-like precipitate of sigma in these alloys.

It is concluded that, from a practical point of view, the most important part of this ternary system is the extensive alpha-solid-solution field. Several commercially important alloys are based on the chromium-cobalt-nickel alpha phase, modified by additions of

iron, tungsten, molybdenum, carbon, and other elements.

See also following abstract.

E. L. KAMEN and P. A. BECK: 'Survey of Portions of the Cobalt-Chromium-Iron-Nickel Quaternary System.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 2603, Feb., 1952; 62 pp.

This Note reports the second part of the investigation referred to in the previous abstract. Iron was used, as the fourth element, in amounts up to 30 per cent., in order to include the range of commercial alloys based on this quaternary system. During the investigation it was found that one of the relevant ternary systems, cobalt-chromium-iron, had not previously been fully studied: a survey of that system was therefore included in the present work.

From the survey of the portion of the quaternary diagram at 1200°C. these conclusions are drawn:

The system comprises an extended range of face-centred-cubic (alpha) solid solutions based on the cobalt-iron binary system, and another extended range of body-centred cubic (epsilon) solid solutions based on chromium-iron solid solutions containing more than 12 per cent. chromium. The chromium-cobalt sigma phase extends into the ternary system, taking up to a maximum of 18 per cent. iron in solid solution. The three solid solutions co-exist in three two-phase fields and a narrow three-phase field. The alpha phase, in almost its whole field, partially or wholly transforms on cooling from 1200°C. to room temperature; it is probably of a martensitic nature.

The isomorphous cobalt-chromium and iron-chromium sigma phases form a continuous series of solid solutions with each other at 800°C.: this ternary sigma solid solution field is wider at 800°C. than at 1200°C. In cobalt-chromium-nickel alloys the alpha solid solution has a somewhat smaller extension at 900°C. than at 1200°C. At 900°C. the chromium-cobalt beta phase extends into the ternary system and takes up to a maximum of 3 per cent. of nickel into solid solution. A martensitic transformation not suppressible by quenching, similar in microstructure to that described for the chromium-cobalt-iron alloys, was found to occur in binary cobalt-chromium alpha alloys and in ternary cobalt-chromium-nickel alpha alloys containing up to about 24 per cent. nickel. At higher nickel contents this transformation is suppressed.

The extent of the alpha solid-solution field at 1200°C. in the chromium-cobalt-nickel-iron quaternary system was studied at 10, 20 and 30 per cent iron contents. With increasing iron, the solubility of chromium in the alpha phase decreases, but the chromium-cobalt-nickel ratios remain nearly the same. The martensitic transformation observed in ternary cobalt-chromium-iron alloys was also found in quaternary cobalt-chromium-iron-nickel alpha-phase-boundary alloys. As the iron content in the alpha-boundary alloys of the quaternary system was increased the nickel content required to suppress the transformation decreased. Transformation in quaternary alloys containing 10 per cent. of iron was suppressed by 13-18 per cent. of nickel, and in alloys containing 20 and 30 per cent. of iron by 8-13 per cent. of nickel.

Effects of Cold-Work on Creep Properties of Nickel-Chromium-Cobalt-Iron Alloys

D. N. FREY, J. W. FREEMAN and A. E. WHITE: 'Fundamental Effects of Cold-Work on Some Cobalt-Chromium-Nickel-Iron-base Creep-Resistant Alloys.' *Nat. Advisory Committee for Aeronautics, Tech. Note* 2586, Jan., 1952; 12 pp.

The report is the fifth in a series dealing with the fundamental factors influencing the creep properties of high-temperature alloys for use in aircraft gas turbines. Previous reports have covered the effects of chemical composition, precipitation-hardening and cold-working (*N.A.C.A. Tech. Notes* 2449, 1940 (*later Report* 1001), 2385 and 2472).

An earlier investigation (*Tech. Note* 2472) had shown that improvement in creep properties resulting from cold-working of low-carbon N-155 alloy was the result of the introduction of internal stresses. Such stresses were associated with broadening of X-ray diffraction lines, and it was found that increasing degrees of cold-reduction effected improved creep-resistance up to the amount which caused significant X-ray line sharpening (interpreted as internal-stress relaxation) to occur at the creep-test temperature. It was concluded that the maximum temperature at which cold-working can be expected to improve resistance to creep will be the maximum temperature at which appreciable internal stresses are retained during test or service. From the results obtained, 'cold-working' was re-defined as 'working at any temperature for which no appreciable internal-stress relaxation occurs during the working operation or during cooling after such working'. A check of temperature-dependence of the influence of 'cold-working' on creep-resistance confirmed this assumption.

The report now published describes work carried out to ascertain the influence, on response to cold-working, of variation in chemical composition. Measurements were made of the effects of additions of tungsten (at three levels) and of a combination of tungsten, niobium and molybdenum,* on the behaviour of a 20-20-20 chromium-nickel-cobalt-iron alloy.

Creep measurements and a study of line-sharpening and internal-stress relaxation effects in these alloys, details of which are given, showed that the effects of cold-working on creep-resistance of all the materials was similar, from the standpoint of the temperature range over which cold-working could be expected to be beneficial (up to 1600°F.: 870°C.) and also the maximum amount of cold-working (15-40 per cent.) which could be used to improve creep properties at about 1200°F. (650°C.).

Nimonic 95

'Nimonic 95.' *Foundry Trade Jnl.*, 1952, vol. 92, Apr. 10, p. 397.

The Mond Nickel Company announces a new alloy in the Nimonic series. Nimonic 95 has been developed from the nickel-cobalt-chromium alloy 90 (see D.T.D. specification 747), but has an increased addition of hardening elements, designed to provide the same strength as Nimonic 90, at operating temperatures

* Alloy corresponding in composition to commercial low-carbon N-155.

some 50°C. higher than those at which the 90 alloy can be used. Improved methods of manufacture and processing have been developed to make possible hot-working and machining of the stiffer alloy, which is now in production at the works of Messrs. Henry Wiggin and Company, Ltd.

A note in *Motor Ship*, 1952, vol. 33, May, p. 81, points out that Nimonic 95 is highly suitable for use in marine, as well as aircraft, gas turbines.

Titanium-Carbide/Nickel Ceramals

A. L. COOPER and L. E. COLTERYAHN: 'Elevated Temperature Properties of Titanium Carbide Base Ceramals containing Nickel or Iron.' *Nat. Advisory Committee for Aeronautics, Research Memorandum E*51110, Dec. 3, 1951; 47 pp.

The report describes an investigation of the properties of commercially produced hot- and cold-pressed compacted materials prepared from titanium carbide mixed with nickel or iron powders in proportions designed to produce bodies of the following nominal weight per cent. composition: nickel 15, 20, 25 and 30; iron 10, 20 and 30. Cold-pressing was at 50,000-60,000 p.s.i. (22·35-26·8 tons per sq. in.), at room temperature, after which the compacts were vacuum-sintered at 2700°-2800°F. (1483°-1538°C.). The hot-pressed bodies were compacted at 2,000 p.s.i. (0·8 ton per sq. in.) at 2900°-2970°F. (1593°-1631°C.) in graphite moulds.

Examination of the materials so prepared comprised investigation of microstructure, density measurements, oxidation tests (1800°, 2000° and 2200°F.: 982°, 1093° and 1204°C., in stagnant air, for times up to 150 hours), and determinations of modulus of rupture, tensile strength and thermal-shock resistance.

In the oxidation tests, unalloyed titanium carbide and the nickel and iron ceramals were found to follow general oxide-growth laws. Two stages of oxidation were observed, the second approximating to the parabolic growth law. In general, nickel ceramals exhibited better oxidation-resistance than iron ceramals; addition of either nickel or iron to titanium carbide lowered resistance to oxidation. At 1800°F. (982°C.), however, both types of ceramal showed increased adherence of oxide and resistance to cracking, as compared with titanium carbide alone, and the same was true of the nickel ceramals at 2000°F. (1093°C.).

At 2000°F. a nickel ceramal containing 13·3 per cent. nickel had an average tensile strength of 16,150 p.s.i. (7·2 tons per sq. in.): the corresponding value for an 11·8 per cent. iron ceramal was 12,500 p.s.i. (5.57 tons per sq. in.). Higher additions of either metal lowered the tensile strength. The highest value obtained for unalloyed titanium carbide was 16,450 p.s.i. (7.35 tons per sq. in.).

Ceramals containing 13·3 to 22·7 per cent. of nickel survived 100 cycles of thermal-shock testing, but iron ceramals failed in 85-97 cycles: addition of either metal markedly increased the thermal-shock resistance of the carbide. Microscopic study of specimens after tensile and thermal-shock test showed that the path of fracture progressed approximately 50 per cent. inter- and 50 per cent. trans-granularly.

Sigma Phase in 25-15 Chromium-Nickel Steel

R. E. LISMER, L. PRYCE and K. W. ANDREWS: 'Occurrence of Sigma Phase in a High Chromium-Nickel Steel and the Effect of Carbon Content.' *Jnl. Iron and Steel Inst.*, 1952, vol. 171, May, pp. 49-58.

Report of research carried out in the laboratories of The United Steel Companies, Stocksbridge.

The paper is introduced by a brief discussion of difficulties inherent in etching of the austenitic steels for detection of sigma. Study of this aspect of the subject has resulted in establishment of a satisfactory technique, which is described: it was used in the experiments reported. It is generally found necessary to use at least two etching reagents, and the verification of constituents by X-ray analysis is a valuable additional confirmation.

The investigation reported was concerned with occurrence of sigma phase, and the influence of varying carbon content (0·06-0·29 per cent.) in a commercial 25-15 chromium-nickel steel re-heated at 700° and 900°C. after initial solution treatments at temperatures within the range 950°-1250°C. In addition to microscopical examination of all specimens and X-ray examination of selected samples, a simple magnetic balance was used as a test for the presence of untransformed ferrite.

The steels used were made in an experimental high-frequency furnace and were cast into 2½-in. square ingots, which were forged to ½- to ¾-in. dia. bar. Specimens ¼-in. long were taken from each cast and were prepared for microscopical examination after the following heat-treatments:—

(i) Solution treatment at 950°, 1050°, 1150° and 1250°C., for 4 hours, followed by water quenching.

(ii) Treatment as in (i), with further heating at 700° and 900°, for periods of 4, 100, 1000 and 2000 hours, followed by air cooling.

A detailed account is given, in tabular form with commentary, of the structural condition of the steels after the respective treatments, and the report is illustrated by a series of over 80 photomicrographs.

Some of the major conclusions drawn are summarized below:—

(1) Increasing carbon in this type of steel caused decrease in the amount of ferrite in the structures obtained by solution treatment at temperatures between 950° and 1250°C., after soaking for 4 hours. The ultimate result of increase in carbon was to produce completely austenitic structures at the highest temperature, 1250°C. The structures obtained in the steels after solution treatment were:—

(i) *Austenite and ferrite* in steels containing 0·06 and 0·09 per cent. of carbon, solution-treated at 1050°-1250°C.

(ii) *Austenite and carbide* in steels containing 0·19 and 0·29 per cent. of carbon, solution-treated at 950°-1150°C.

(iii) *Austenite* in steels containing 0·19 and 0·29 per cent. of carbon, solution-treated at 1250°C.

(2) Sigma phase formed in all three of these

structures after prolonged re-heating at 700° and 900°C. With increase in carbon content and rise in solution-treatment temperature, beginning and development of sigma-phase formation was generally slower. Mode of occurrence of the sigma phase developed on prolonged re-heating is governed by the structures of the steel resulting from the initial solution treatment.

(3) Formation of sigma phase in the duplex austenite-ferrite structures takes place in the ferrite regions and formation is relatively rapid. Formations of sigma phase within an austenite or austenite-carbide structure are essentially similar in nature, due to primary precipitation of carbide on re-heating at 700° or 900°C. A hypothesis is postulated to account for the observations made.

(4) Sigma phase, carbide, and ferrite were identified by X-rays in residues from electrolytic solutions of treated samples. The results are in general agreement with those of microscopical observations.

The constitution of the steels examined is discussed in relation to available equilibrium data, and the effects of carbon and of silicon are especially considered. The authors conclude that further work on commercial materials is necessary in order to establish satisfactorily the influence of minor elements.

Adherence of Glass to Metals and Alloys

R. C. DARTNELL, H. V. FAIRBANKS and W. A. KOEHLER: 'Investigation of the Adherence of Glass to Metals and Alloys.' *Jnl. Amer. Ceramic Soc.*, 1951, vol. 34, Nov., pp. 357-60.

The investigation reported was directly related to the interests of the glass-container industry. The materials tested comprised cast iron, stainless steel, carbon steels, commercially pure metals (molybdenum, chromium, copper, platinum, cobalt, titanium, silver, aluminium, vanadium, gold, beryllium, nickel and tungsten), Inconel (nickel-chromium-iron alloy), ferro-vanadium, brass, chromium-molybdenum alloy, Monel and K Monel. Apparatus and technique used in determining the adherence temperatures of these materials, and of a carbon of electrode grade, are described and illustrated. Molten glass beads were dropped, through 2½ inches, onto the metal surface, previously heated to a temperature of 200°F. (111°C.) above the sticking temperature and inclined at an angle of 45 degrees. The metal sample was allowed to cool slowly as molten glass beads were dropped on it at intervals of one minute. Time of adherence of each molten glass bead and the corresponding temperature of the metallic sample were recorded: the adherence temperature was determined as the point at which the adherence curve deviated from the line of free fall. This indicated the maximum metal temperature at which the glass did not adhere to the metal.

Nickel, tungsten, Monel and K Monel proved to have the highest adherence temperatures of all the materials tested and were therefore selected for further experiments in which a 'persistence' test was made, at specified constant temperatures below the adherence temperatures, to determine how many molten glass beads could be dropped on the surface of the heated metal sample before adherence of the beads occurred. A combination of corrosion and erosion ultimately led to adherence: the rate of the corrosion-erosion deterioration was found to be dependent on the affinity of the molten glass and the parent metal for the metallic oxide formed. The persistence values obtained for the respective metals and alloys varied according to whether amber soda-lime or clear soda-lime glass beads were used: the latter caused the more rapid erosion. Tungsten and Monel gave the most promising results in the persistence tests.

Tests for Determining High-Temperature Behaviour

L. B. PFEIL: 'High-Temperature Materials: Tests Used as Criteria of Service Behaviour.' *Schweizer Archiv*, 1952, vol. 18, Mar., pp. 88-97.
Reprint of paper presented before Schweizerischer Verband für die Materialprüfungen der Technik, April, 1951.

The properties most important in materials for high-temperature service are creep-resistance, fatigue strength, resistance to corrosion by the surrounding atmosphere, and resistance to thermal shock. Methods used to assess these properties of high-temperature materials, and the probable behaviour of the materials under service conditions, are discussed in some detail. The discussion is illustrated by data on Nimonic (nickel-chromium-base) alloys, austenitic heat-resisting steels, and other materials which have been developed for high-temperature use. The importance of close co-operation between metallurgists and engineers is emphasized as a factor essential to further advancement in the high-temperature field.

Supply and Use of Nickel: I.M.C. Report

See abstract on p. 146.

Nickel Alloy Cast Iron Pots for Melting Aluminium

See abstract on p. 155.

Solubility of Carbon in Austenitic Nickel-Chromium Steels

S. J. ROSENBERG and C. R. IRISH: 'Solubility of Carbon in 18 per cent. Chromium/10 per cent. Nickel Austenite.' *Jnl. of Research, Nat. Bur. Standards*, 1952, vol. 48, pp. 40-8.

Although the extra-low-carbon nickel-chromium steels (carbon 0·030 per cent. max.) show marked improvement in resistance to intergranular corrosion, by comparison with similar steels in which carbon is of the order of 0·07 per cent., even the E.L.C. grades precipitate carbides under certain conditions of time and temperature of exposure. It is apparent that complete immunity to this form of deterioration can be secured only with carbon contents lower than the limit of solid solubility, and it is now generally believed that this limit is below the value of 0·02 per cent. which has been usually assumed. The work described

in this report was undertaken to establish a correct figure.

The account of the experimental determinations is introduced by a summary of data obtained by earlier investigators, covering a temperature range of 1400°-2200°F. (760°-1204°C.). The 18-10 chromium-nickel-iron alloys used in the present research were prepared from high-purity metals (analyses are given), and the carbon was varied over the range 0·007-0·30 per cent. Melting and casting operations were conducted in vacuo.

The alloys so prepared were subjected to various mechanical and thermal treatments, and the extent of the carbide precipitation after the respective cycles of treatment was determined by metallographic examination. (Initial attempts to use measurements of magnetic permeability, lattice parameter, electrical resistivity, and electrolytic-solution potential, X-ray examination, and chemical analysis of chromium carbides, as a means of determining the limit of carbide solubility, had proved unsatisfactory.) The report is illustrated by a large number of photomicrographs showing the condition of alloys of various compositions, after various treatments.

It was found that with a carbon content of 0·007 per cent. solubility of carbides was substantially complete between 1300° and 1400°F. (704° and 760°C.). Complete solution of the last minute traces of carbides was, however, not effected until 1700°F. (926°C.). Solubility increased with rise in temperature and at the maximum temperature used (1975°F. : 1077°C.) solubility of carbon was approximately 0·08 per cent. The curve resulting from the studies reported shows that the solubility of chromium carbide in alloys of the 18-10 per cent. type is appreciably lower than has previously been reported. On the basis of this curve it is considered that type 304 E.L.C. steels (chromium 18, nickel 10, carbon 0·03 max., per cent.) can be effectively annealed at 1700°F. (926°C.), but that Type 304 steel of normal carbon content (0·07 per cent. max.) should be annealed at temperatures above 1900°F. (1036°C.). The existence of sigma as a stable phase in the low-carbon alloys, particularly in the range of about 1000°- 1300°F. (538°-704°C.) was established.

Potential Measurements as a Criterion of Susceptibility of Stainless Steels to Selective Corrosion

L. R. STANDIFER, F. H. BECK and M. G. FONTANA: 'Relations between Solution Potentials and Susceptibility of Stainless Steel to Selective Corrosion.' *Ohio State Univ., Engineering Experiment Station News*, 1951, vol. 23, Oct., pp. 17-19, 47.

Selective attack on stainless steels is principally of two types: (1) pitting, as encountered in chloride solutions, and (2) intergranular corrosion which occurs on 'sensitized' steels in certain solutions (e.g., nitric acid), a type of attack generally attributed to existence of a chromium-depleted area which preferentially corrodes.

In the research reported in this note (carried out under contract for the U.S. Office of Naval Research), an attempt was made to determine the extent to which potential measurements can be used to gauge susceptibility to either type of corrosion. Two forms of test were made: measurement of micro-potentials and of mass potentials. Micro-potentials were obtained by punching a small hole through a transparent insulating film, using a Bergman micro-hardness tester. Mass solution potentials were observed in a cell in which the atmosphere over the electrolyte could be controlled. Measurements of both types were made on various stainless steels which had been sensitized to varying degrees by suitable heat-treatments. The electrolytes used were NaCl, $Fe(NO_3)_3$, $FeCl_3$, 0.1*N* HNO_3, 65% HNO_3 and 10% H_2SO_4.

Gross potential measurements failed to reveal any indication of susceptibility to *intergranular attack*, and micro-potentials also gave no useful information except in the case of Type 316 steel in sulphuric-acid solution, but the potentials of stainless steel in chloride solutions give qualitative indication of the degree of *pitting* corrosion which is being undergone by stainless steels. Some typical results are quoted from both series of tests.

Nickel-base Non-Ferrous Casting Alloys

See abstract on p. 150.

Nickel-containing Materials for Handling Sodium Chlorate

R. MATTAIR: 'Sodium Chlorate: How to Handle it Safely.' *Paper Industry*, 1952, vol. 33, Jan., pp. 1187-8.

Use of chlorine dioxide for bleaching pulp has recently created some interest, in the paper industry, in sodium chlorate as one of the sources of the bleaching agent. This article gives a condensed, practical summary of hazards associated with sodium chlorate, its properties, precautions required in handling, methods of storage, and related corrosion problems. It is noted that 'experience in the handling of hot neutral or alkaline sodium chlorate solutions has indicated that nickel and stainless steel, Type 304 or 316, are very resistant to corrosion, and are suitable for tanks, pumps and lines. Type 28 aluminium, used in pipe lines and in filter presses, is also quite satisfactory, although it is subject to electrolytic corrosion and must be protected with non-conductors such as rubber or Bakelite. Ordinary steel or cast iron tanks are more subject to corrosion, particularly in the case of open tanks with fluctuating liquid levels, in the area of change of level. The life of such tanks is lengthened considerably by addition, to the chlorate solution, of 500 parts per million of sodium dichromate and 10-20 parts per million of sodium silicate.'

Nickel-containing Materials in Water Filters

'Filtration Provides Cleaner Fluids for Industry.' *Nickel Topics*, 1952, vol. 5, No. 3, p. 5.

Water used for operation of a large number of industrial processes is, of necessity, drawn in many cases from contaminated waters containing solid matter. This note describes a filter designed for conditioning water to be fed to cooling towers, heat-exchangers, high-pressure sprays and other machinery

which must be kept free from contact with abrasives or contaminants.

Filter units of the type described have been used for many years in handling water from Lake Michigan, and have also given good service in oil refineries and other plant. The filter elements consist of stationary cylindrical cages or cartridges, cast in Type 2 Ni-Resist containing nickel 20, chromium 2, per cent. In the outer surfaces of these are screw threads, into which are wound wires of stainless nickel-chromium steel. The pitch of the screw threads and the diameter of the wire determine the degree of filtration, by controlling the space between the wires. Incoming liquid enters the space between the filter elements and the shell, and passes between the wires, leaving all the coarse solids deposited on the wires, while the filtered water flows downwards to the outlet. Self-cleaning of the filter element is done by means of a small booster pump, which picks up a part of the filtrate and delivers it at increased pressure to a slowly-rotating back-wash nozzle (also cast in Ni-Resist) in the cage. As each section of the elements encounters a momentary reversal of flow all solids are dislodged and settle to a sump, from which they are periodically drawn off by a blow-off valve. This self-maintenance device is found to add greatly to the value of the filters when installed in remote locations. Stainless steel and Ni-Resist have been found to withstand, for long periods, the combination of corrosive and erosive attack involved in such filtering service.

Stainless Steel in Architecture

AMER. IRON AND STEEL INST., COMMITTEE OF STAINLESS STEEL PRODUCERS: 'How and Where to Specify Stainless Steel in Architecture.' *Published by the Institute*, 1951; 20 pp.

The publication is intended as a reference manual for architects, indicating the compositions and properties typical of the various grades of stainless steel; the forms and finishes in which the steels are commercially available, and the individual applications, in building construction, for which such materials are suitable. A guide is given on specification requirements which should be laid down for stainless steel for architectural purposes. The information given will be of practical value to architects when the use of stainless steels for such applications is again permitted.

Spectrographic Analysis of Stainless Steels

M. F. HASLER: 'Analysis of Stainless Steels, covering an Extensive Range of Contents, by Means of the Quantometer.' *Colloque International de Spectrographie de Strasbourg*, Oct., 1950, pp. 75-9.

Paper contributed to symposium organized by Groupement pour l'Avancement des Méthodes Spectrographiques des Produits Métallurgiques.

Describes procedure for analysis of a wide range of stainless steels, using the Quantometer developed by the Applied Research Laboratories, Glendale, California. The methods are applicable to estimation of the following elements, over the ranges shown: iron 50·0-85·0, chromium 10·0-30·0, nickel 0·1-25·0, manganese 0·1-2·0, silicon 0·1-1·0, molybdenum 0·1-2·5, titanium 0·1-2·0, niobium 0·1-1·0, tungsten 0·5-2·0, per cent. See also closely related paper by the same author, entitled 'Convenient Method of Calculating in Spectrum Analysis by a System of Multiplying Factors', *ibid.*, pp. 61-73.

Pre-Heating Practice for Welding of Steels

See abstract on p. 158.

Welding of Steel Castings: Recommended Procedure

See abstract on p. 158.

The Salt-Spray Test

See abstract on p. 149.

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